STUDY OF POME AND MIXTURE OF POME AND PALM OIL FIBRE CHARACTERISTICS AND POTENTIAL FOR BIOMASS ENERGY

by

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Dissertation submitted in partial fulfillment of
the requirements for the
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Certification of Approval

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in the project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained hereby have not been undertaken or done by unspecified source or persons.

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ABSTRACT

Malaysia is the second world biggest producer and exporter of palm oil and palm oil products. In 2008, Malaysia produced 17.7 million tonnes of crude palm oil (CPO) on 4.5 million hectares of land. In the production of CPO, by products will be produced and create environmental issues. These by products, which have high market value and biomass values, are not fully utilized. The major by products produced include palm oil mill effluent (POME), empty fruit bunches (EFB), mesocarp fibre and palm oil frond. Since the supply of POME is content and large quantity, the POME has the potential of becoming new source of biomass energy. This research is conducted with the objectives to study the elements content and energy level of the samples (POME, mesocarp fibre and the mixture of POME and mesocarp fibre at different ratio) and to find out the potential waste reduction from POME for zero waste in palm oil industry. The scope of the research is to study the characteristics of the POME and its potential of becoming biomass energy. This research is conducted experimentally through standard tests to determine the characteristics of the samples. Element content test is carried out to determine the carbon, hydrogen, nitrogen and sulphur in the samples. Burning test is conducted to determine the ignitability and ash content of the samples. The calorific values of the samples are determined by using bomb calorimeter. The brittleness of the briquettes of samples is determined by carrying out drop test. The results show that the dry raw POME has the highest calorific value among the samples and has low contents of nitrogen and sulphur. The raw POME has the potential of becoming new biomass energy and the objectives are archived.

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ABBREVIATION

Bhd.	-	Berhad
BOD	-	Biochemical Oxygen Demand
C	-	Carbon
CHNS	-	Carbon, Hydrogen, Nitrogen and Sulphur
COD	-	Chemical Oxygen Demand
CPO	-	Crude Palm Oil
CSTR	-	Continuous Stirred Tank Reactor
CV	-	Calorific Value
EFB	-	Empty Fruit Bunches
FFB	-	Fresh Fruit Bunches
H	-	Hydrogen
KCE	-	Konzen Clean Energy Sdn. Bhd.
MARDI	-	Malaysian Agriculture Research Development
N	-	Nitrogen
PHA	-	Polyhydroxalkanoate
PK	-	Palm Kernel
POF	-	Palm Oil Frond
POME	-	Palm Oil Mill Effluent
PTE LTD	-	Private Limited
S	-	Sulphur
Sdn.	-	Sendirian
UPM	-	Universiti Putra Malaysia
USDA	-	United State Department of Agriculture
UTP	-	Universiti Teknologi PETRONAS

CHAPTER 1

INTRODUCTION

1.1 Introduction

In 2009/2010, about 140 million tons of vegetal oils were produced around the world. About 70% of 140 million tons of vegetal oils are consists of soya oil (26% or 38 million tons), palm oil (18% or 45.9 million tons), rape oil (12% or 22.1 million tons) and sunflower oil (13% or 11.3 million tons).[1] However, according to the Oil Crop Year Book 2011, which was published by United State Department of Agriculture (USDA), the palm oil production has become the main oil production of the world. Figure 1.1.1 shows the world vegetable oil production from year 2006 to 2011.

POME is one of the by products in the production of crude palm oil (CPO). The production of one tonne of CPO will produce about 3.5m^3 of POME.[2] If the POME is not handled well, it will create a big impact to the environment and this will be explained detail in section 1.2. This research is to test the energy level of palm oil mill effluent (POME) by direct burning of POME according to different quality and mixture of the samples. The research is aim to find out the potential biomass energy of POME which can lead towards zero waste.

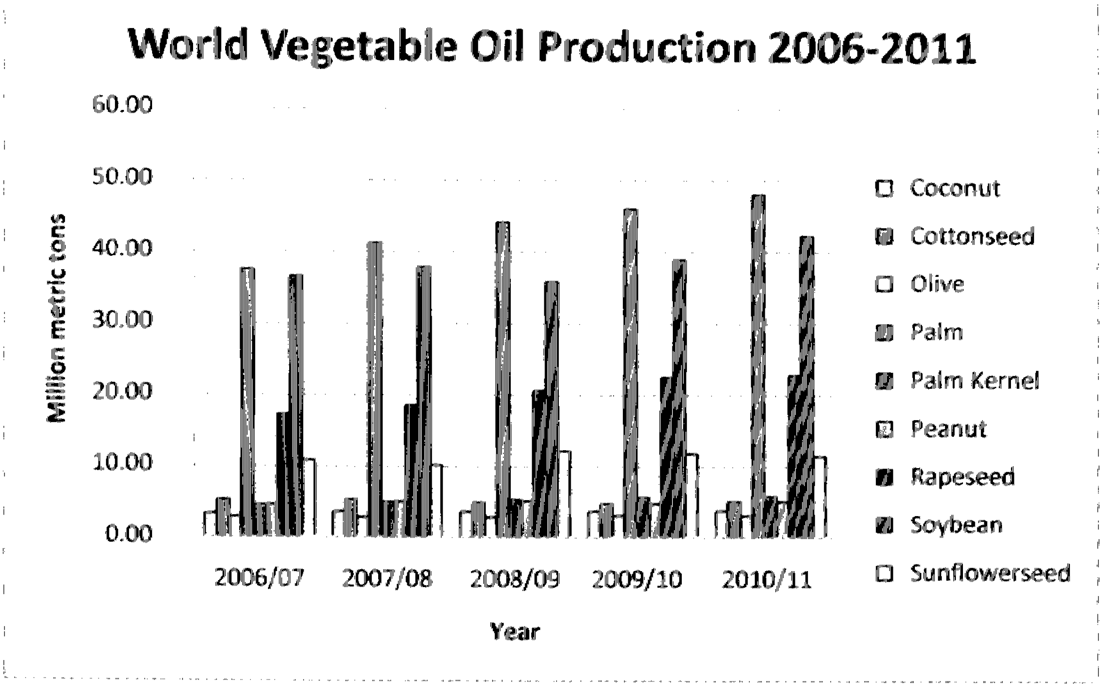


Figure 1.1.1. World vegetable oil production from 2006 to 2011.[3]

1.2 Problem Statement

While extracting the CPO from the fresh fruit bunch (FFB) of the oil palm, the process will also generate by products such as empty fruit bunch (EFB), mesocarp fibre, shell and POME. In the processing of every tonne of FFB, about 23% of EFB, 12% of mesocarp fibre, 5% of shell and 60% of POME will be generated.[4] To produce a tonne of CPO, around 6 tonnes of palm oil frond (POF), 1 tonne of palm trunks, 5 tonnes of EFB, 1 tonne of press fibre (also known as mesocarp fibre), half tonne of palm kernel endocarp, 250kg of palm kernel press cake and 100 tonnes of POME will be produced.[5] The production of one tonne of CPO will produce about 3.5m^3 of POME. In year 2009, it was estimated about 43.8 million m^3 of POME was produced in Malaysia with the production of 17.56 million tons of CPO.[6]

POME can be considered as the waste from the production of palm oil and will have a big impact to the environment. The biochemical oxygen demand (BOD) level and chemical oxygen demand (COD) level of POME are 25000 mg/l and 50000 mg/l respectively. Besides, the POME also contains high amount of solids (40500 mg/l) and oil and grease (4000 mg/l).[7] Table 1.2.1 shows the characteristics and discharge limits of POME.

Parameters	POME (range)	POME (means)	Discharge standard (1-1-1984 and thereafter)
Temperature (°C)	80 – 90	85	45
pH	3.4 – 5.2	4.2	5.0 – 9.0
Oil and grease	130 – 18000	6000	50
BOD	10250 – 43750	25000	100
COD	15000 – 100000	51000	-
Total solid	11500 – 79000	40000	-
Suspended solid	5000 – 54000	18000	400
Total volatile solid	9000 – 72000	34000	-
Total nitrogen	180 – 1400	750	200
Ammoniacal nitrogen	4 – 80	35	150

Table 1.2.1. Characteristics of POME and discharge limits. All parameters are in mg/l except temperature and pH. The BOD of sample is incubated for 3 days at 30°C.[6]

As mention earlier, about one tonne of mesocarp fibre will be produced with the production of one tonne of CPO. Recently, the mesocarp fibre and shell are used as boiler fuel in the palm oil mills to produce steam and for power generation purpose.[8] However, the fibre has high moisture content and this will reduce the efficiency of the burning. The fibre has moisture content of 37.2% and this will decrease its calorific value due to incomplete burning. Table 1.2.2 shows the physical properties of the mesocarp fibre, EFB and kernel shell.

		Calorific value HHV MJ/kg		Elementary and ash analyses (wt%) using dried sample					
Biomass	Moisture (%)	Wet	Dry	C	H	N	S	O	Ash
EFB	57.2	10.57	17.02	45.53	5.46	0.45	0.044	43.40	5.12
Mesocarp fibre	37.2	13.33	19.61	46.92	5.89	1.12	0.089	42.66	3.32
Kernel shell	21.4	16.14	19.78	46.68	6.86	1.01	0.060	42.01	4.38

Table 1.2.2. The physical properties of the mesocarp fibre, EFB and kernel shell. The fibre samples are of 1mm in diameter irregular bowl-like chip of 10 mm long and 2 mm thick. [10]

1.3 Objectives

The objectives of this research are:

i. To study the elements content of the POME and mesocarp fibre
ii. To study the energy level of the POME mixed with different percentage of mesocarp fibre.
iii. Potential waste reduction from POME for zero waste in palm oil industry.

1.4 Scope

The scope of this research is to study the characteristics of POME and its potential of becoming biomass energy.

1.5 Equipment Required

The equipment required to carry out this research are as below:

i. Bomb calorimeter – to study the calorific value of the samples.
ii. XRF / CHNS machine – to evaluate the element contents of the POME and fibre.
iii. Grinder – to grind the fibre.

iv. Autopellet press machine – to produce briquettes of samples

v. Oven – to remove the moisture contents of the samples

vi. Bunsen – to light the samples for burning test purpose

1.6 Feasibility of the Study

The research is a zero cost research whereby the samples are collected from a palm oil mill, which is near to the university. The equipment required to carry out the experimental works are available in the university. The research will be carried out according to the planning and allocated time frame by following the Gantt chart in section 3.9 and section 3.10.

CHAPTER 2

LITERATURE REVIEW

2.1 Production of Crude Palm Oil (CPO)

When the fresh fruit bunches (FFB) are mature, the FFB will be harvested and will be sent to the factory to undergo palm oil milling process to produce crude palm oil (CPO) and palm kernel.

In the factory, the FFB will be steamed in the pressurized vessels, which at pressure of 3 bars pressure, and this process is known as sterilization process. The objectives of this process are to arrest the formation of free fatty acids from the FFB and to prepare the fruit for subsequent processes.

The FFB will then be stripped in a rotating drum thresher to remove the fruit from the bunch. The empty fruit bunches will be sent to the plantation for mulching purpose while the fruits are sent to the press digesters.

The fruits, which are inside the press digesters, are heated by using steam and are stirred continuously. This is aim to loosen the oil – bearing mesocarp from the fruit nuts and to break open the oil cells in the mesocarp. Next, the digested mash is pressed to extract the oil by using screw presses. This will produce palm oil and press cake. The press cake will be sent to the kernel plant to recover the kernel.

The palm oil will be diluted and pumped to the vertical clarifier tanks. The oil will be filtered and purified to remove the dust, dirt and moisture. This will produce crude palm oil and sludge. The oil will then be dried in the vacuum drier. The sludge will be fed into the bowl centrifuges for further oil recovery and the recovered oil will be recycled to the clarifiers to undergo purifying process. The water and sludge mixture is known as palm oil mill effluent (POME) will be treated in effluent treatment plant.

The press cake which is produced in the oil extracting process is sent to the kernel plant. The press cake is conveyed to the depericarper. In this process, the fibre and nuts are separated. The fibre is burned as fuel in the boiler while the nuts are cracked into shell and kernel. The kernel will be dried and stored.[9]

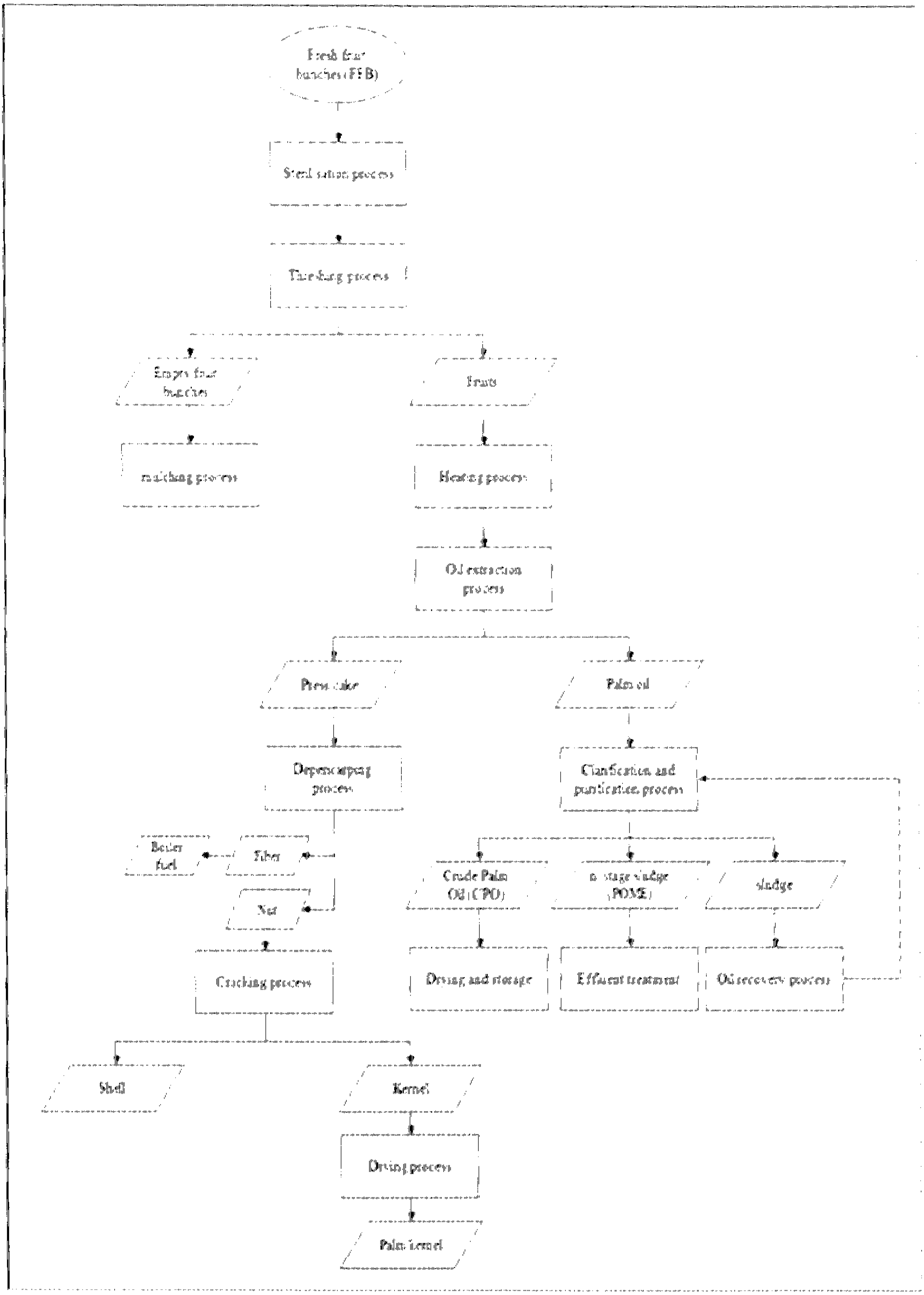


Figure 2.1.1. The process flow of the processes involved in producing crude palm oil and the by-products.

2.2 Current Technologies

As mention in section 1.2, raw POME creates serious impact to the environment. Besides, large quantity of POME will be generated with the production of CPO. Thus, several alternatives are developed to solve the problem. These alternatives include:

i. POME treatment systems
ii. Usage of gas methane (CH_4)
iii. POME as animal feed
iv. Chemical processing into bio – acids and organic acids for bio – plastics
v. Conversion of POME to organic fertilizer

The mesocarp fibre can be used for purposes such as:

i. boiler fuel
ii. production of organic fertilizer[11]

2.2.1 POME treatment systems

POME cannot be discharged into the environment without any treatment due to its characteristics and elements. By using the conventional technology, the POME is placed in open lagoons and undergoes anaerobic and aerobic treatment. The biogases, consists of methane (CH_4), carbon dioxide (CO_2) and hydrogen sulphide (H_2S), will be produced at the open lagoons and these biogases will be released into the atmosphere.[12]

At Sime Darby Plantation, there have a series of effluent treatment systems are applied on POME before discharging the POME. These treatment systems include anaerobic digestion system, extended aerobic process and bio reactor system.[13]

2.2.2 Usage of gas methane (CH_4)

The gas methane, which is also known as green house gas, produced in open lagoons will be used for electric generation purpose. Keng Seng (M) Bhd. has developed

KS™ Anaerobic Digester Technology to treat the POME and at the same time to capture the gas methane produced. This technology is able to produce 11200 m^3/day of biogas (62.5% of CH_4, 37% of CO_2 and 1500-3000 vppm of H_2S) from 400 m^3/day of POME. The energy rate of gas methane produced is about 2.2×10^8 kJ/day or 6.13×10^4 kWh/day.[14]

AslicNova Pte Ltd., a company which provides renewable palm biomasses and feedstocks to customers, works with palm oil mills to capture methane gas for electricity generation purpose and the electricity is used for plant and machinery usage.[15]

2.2.3 POME as animal feed

Filtration process or membrane process is done on the POME to separate out the solids, known as palm oil sludge, and waste water. The palm oil sludge is rich of protein, carbohydrate, nitrogenous compounds, lipids, amino acids, fatty acids, minerals and other essential nutrients.[16] Table 2.2.3.1 shows the chemical composition of palm oil sludge.

Composition	**Chemical composition**
Moisture, %	6.9
Crude protein (N x 6.25), %	12.4
Crude fiber, %	15.2
Ether extract, %	24.1
Ash, %	11.2
Nitrogen – free extract, %	46.7
Calcium, %	0.28
Phosphorus, %	0.18
Magnesium, %	0.25
Iron, mg/l	1757
Copper, mg/l	62
Zinc, mg/l	1075
Gross energy, MJ/kg	19.6

Table 2.2.3.1. Chemical composition of palm oil sludge.[17]

It is proved by Malaysian Agricultural Research Development (MARDI) that the palm oil sludge can be used as food for the sheep if the sludge is dried to moisture content of 7%.[17] Besides, the palm oil sludge can be used as the fish feed due to the high protein of palm oil sludge. It is also economically to use palm oil sludge as fish feed if compared with the imported fish feedstuffs.[18]

2.2.4 Chemical processing into bioacids and organic acids for bioplastics

Up to date, the bioplastic research group of Universiti Putra Malaysia (UPM) has successfully converted the POME into polyhydroxalkanoate (PHA). PHA is a biopolymer thermoplastic that is biodegradable.[19] The bioplastic is biodegrade to the carbon dioxide and water within a few weeks when is disposal to the environment or in the soil.

2.2.5 Conversion of POME into fertilizer

POME is converted into fertilizer due to containing organic matter and plant nutrients. The raw POME will undergo treatment to increase the pH to around 8 and lower the BOD value. Then the anaerobic sludge of the treated POME will be carried to the plantation and used as fertilizer.[20] The usage of POME as fertilizer will enrich the phosphorus, nitrogen, calcium, magnesium, sodium and potassium of the soil.[17]

2.2.6 Usage of mesocarp fibre as boiler fuel

As mention earlier, the mesocarp fibre is used as boiler fuel to replace the fossil fuel in the steam generation of the palm oil mills. The mesocarp fibre, also known as oil palm mesocarp fibre (OPMF), is produced after the oil extraction process. The oil which losses in the fibre, was around 5 to 6% and this has encouraged the usage of mesocarp fibre as fuel for the boilers in the palm oil mills.[21] By replacing the fossil fuel with the mesocarp fibre, the mill hosts not only can save a lot of money, but also can earn the Certified Emission Reductions (CER) credit through Clean Development Mechanism (CDM) project.[22] Table 2.2.6.1 lists the database for the palm biomass. From the table, we can figure out that material with high moisture content will have lower calorific value due to incomplete burning occurs while burning the high moisture content material.

Sample	Calorific value (kJ/kg)	Ash (%)	Volatile matter (%)	Moisture (%)
Empty fruit bunches (EFB)	18795	4.60	87.04	67.00
Fibre	19055	6.10	84.91	37.00
Shell	20093	3.00	83.45	12.00
POME	16992	15.20	77.09	93.00

Table 2.2.6.1. The database for palm biomass.[23]

2.2.7 Production of organic fertilizer

The mesocarp fibre is natural and non toxic due to the CPO extraction process does not involve any chemical. The mesocarp fibre is then mix with high nitrogen content materials to produce organic fertilizer. Research has been carried out by composting the mesocarp fibre for biocompost production. POME is added gradually to the mesocarp fibre in the composting process. The result shows the final C/N ratio is 12.6 and the final compost has considerable amount of nutrient.[24]

2.3 Biomass Briquetting

The biomass briquetting is the process of producing compact solid from the loose biomass material. Pressure will be applied on the biomass material during biomass briquetting. Heat treatment and binding agents may be applied in the briquetting process. The biomass briquetting has several advantages such as reduce the transportation fee of the raw biomass material and reduce the storing space of the biomass material. Besides, the biomass briquette has constant size and is easy to be handle compare to the raw biomass material.[25]

CHAPTER 3

METHODOLOGY

3.1 Introduction

The overall research is divided into six main parts, which are sample preparation, production of briquettes of samples, study of element content of samples, verification of calorific values of the samples, burning test and drop test.

The equipment required to carry out this research are as below:

i. Bomb calorimeter – to study the calorific value of the samples.
ii. XRF / CHNS machine – to evaluate the elements contain in the POME and fibre.
iii. Grinder – to grind the fibre.
iv. Autopellet press machine – to produce briquettes of samples
v. Oven – to remove the moisture contents of the samples
vi. Bunsen – to light the samples for burning test purpose

3.2 Sample Preparation

The POME and mesocarp fibre are collected from a palm oil mill which is near to Universiti Teknologi PETRONAS. Part of the POME and mesocarp fibre collected will be put in the oven to remove the moisture content. The weights of the samples (before entering the oven), w_1, are weighed and recorded. Then the samples are put in the oven, where the temperature of the oven is set to 105°C, for 24 hours. The weights of the samples (after removing the moisture content), w_2, are weighed and recorded.

The moisture content of the samples can be calculated by using the equation below:

$$moisture\ content = \left(\frac{w_1 - w_2}{w_1}\right) x\ 100\%$$

whereby

w_1 = weights of samples before removing moisture content
w_2 = weights of samples after removing moisture content

Then, the mesocarp fibre is grinded into powder form by using the grinder. The POME sample needs to be kept at the place with temperature below 20^oC to avoid the change of the quality of the POME sample.

3.3 Study of Element Content of Samples

XRF / CHNS machine will be used in the study of element content of the POME and mesocarp fibre. The data collected will be recorded in table and will be compared with reference data.

3.4 Production of Briquettes of Samples

There are 7 types of samples are to be tested. These samples are 100% dry POME, 100% wet POME, 100% dry mesocarp fibre, 100% wet mesocarp fibre and mixtures of POME to mesocarp fibre (at ratio of 75:25, 50:50 and 25:75). Dry samples are the samples where the moisture content is removed while wet samples are the samples where the moisture content is not removed.

10±0.5 gram of each sample is measured and is put in the mould of the autopallet press machine. The load is set to 1500 kilogram force. The mould will then be put in the hydraulic press of the autopallet press machine and the machine is started. Five briquettes will be made for each type of sample. The height of the briquette produced are measured and recorded.

The volume or size of the briquette is determined by using the formula below:

$$Volume, V = \pi r^2 h$$

whereby

r = radius of the briquette

h = height of the briquettes

The weight of the produced sample briquettes will be determined to calculate the density of the samples. The formula to calculate the density is

$$density, \rho = \frac{mass}{volume}$$

3.5 Calorific Values Test

This test will be divided into two sections. The first section is to test the POME and mesocarp fibre after collecting the samples. The objective is to make sure the samples collected can be burned and the calorific value can be determined. Bomb calorimeter will be used in the verification of the calorific values of the samples. 0.8g of the pure POME and mesocarp fibre will be tested for the calorific values. The samples can be used in other processes if the calorific values for the samples can be determined.

The second section is to verify the calorific values of the samples. The briquette will be grinded and about 0.8g of the sample is tested. The weight of the sample is keyed – in by using the prompt screen of the bomb calorimeter before the process is started. The calorific value for the sample, which is shown at the prompt screen of the bomb calorimeter, will be recorded in table. Three tests are run for each type of sample and the process is repeated by using samples with different mixture ratio.

3.6 Burning Test

The objective of the burning test is to test the ignitability and time taken to burn the sample to ash. Bunsen burner set will be used in this test. The briquette is put on the wire gauze and the Bunsen burner is ignited. Every 5 seconds, the briquette will be removed and placed on a piece of tissue paper to test whether the briquette has ignited or not. The briquette is considered to be ignited if the briquette was able to burn through the tissue paper. The interval time is recorded until the briquette is ignited. The ignitability time is equal to the sum of the interval time. To test the time taken to burn the briquette to ash, the briquette is burned and the stop watch is started. When the briquette is burned until become ash, the stop watch will be stopped and the time is recorded. The ash content of the samples will be calculated by using the following formula:

$$ash\ content\ (\%) = \frac{final\ weight}{initial\ weight}\ x\ 100\%$$

3.7 Drop Test

The objective of drop test is to find out the brittleness of the samples. The brittleness of the briquettes plays an important role in the transportation, handling and storing of the briquettes. The test is done by dropping the briquettes of the samples from 1 meter height location for four times per briquette. After every drop, the briquette will be weighted. The results will be recorded and discussed.

3.8 Research Processes Flow Chart

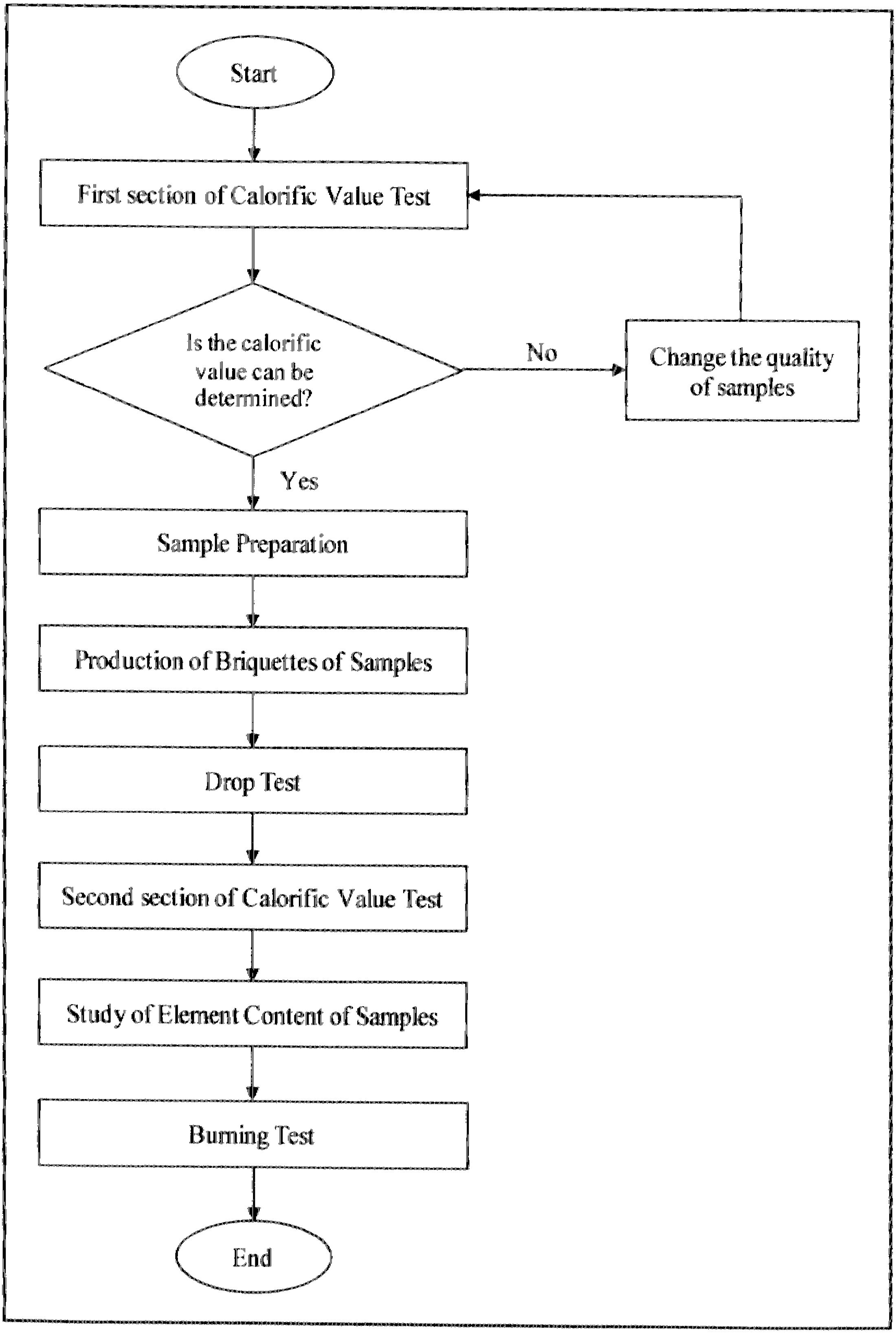


Figure 3.8.1. The research process flow chart.

3.9 Gantt Chart for FYP I (23 May 2011 to 26 August 2011)

Tasks \ Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Topic selection	D													
Topic allocation		D												
Understand the process involved in palm oil processing		D	D											
Send Letter to request for POME sample			D											
Prepare the proposal			D	D	D	D	D							
Submission of proposal							D							
Prepare for Proposal Defence							D	D	D	D				
Proposal Defence											D			
Collect POME sample									X	X				
Collect mesocarp fibre sample									X	X				
Study the characteristics of POME									X	X				
Study the characteristics of mesocarp fibre									X	X	X			
Prepare the interim report											D	D	D	
Submission of interim draft report													D	
Submission of interim report														D

Process D Done X Delay

3.10 Gantt Chart for FYP II (26 September 2011 to 30 December 2011)

Tasks \ Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Collect of POME and mesocarp fibre samples	D													
First section of Calorific Value Test	D													
Sample Preparation	D													
Production of Briquettes of Samples		D												
Drop Test			D											
Second section of Calorific Value Test			D	D	D									
Study of Element Content of Samples			D	X	X	X	X	X	D					
Prepare the progress report	D	D	D	D	D	D	D	D						
Submission of progress report								D						
Burning Test										D				
Submission of FYP poster											D			
Submission of draft report												D		
Submission of project dissertation (soft bound)													D	
Submission of technical paper													D	
Oral presentation														
Submission of project dissertation (hard bound)														

[ ] Process [D] Done [X] Delay

3.11 Feasibility of Plan

3.11.1 Gantt chart

For the time being, all tasks in the Gantt chart for FYP I are running smoothly according to the plan except the collection of POME and palm oil frond samples. This is because the manager of the palm oil mill is busy and this had caused the POME and mesocarp fibre samples are not able to be collected at week 9 (10 July 2011 – 16 July 2011) and the processes to study the elements content of the samples are affected as well. The collection date may change to week 11 or week 12 if the visit to the palm oil plant is not able to be done on week 10 (17 July 2011 – 23 July 2011).

On the other hand, the tasks in the Gantt chart for FYP II are running smoothly according to the plan except the study of element content of samples. The samples had been passed to the technician in charge of the XRF machine in week 3. However, the result of the test is not yet returned from the technician due to the machine was down. The alternative solution of this problem is to change the machine from XRF machine to LECO CHNS machine. The LECO CHNS machine is able to test the carbon, hydrogen, nitrogen and sulphur contents of the samples being tested. The machine is being booked and the test will be carried out in week 9.

CHAPTER 4

RESULT AND DISCUSSION

4.1 First Section of Calorific Value Test

At first, the POME sample collected is end pond POME. However, the calorific value of the sample cannot be determined by the bomb calorimeter. The machine shows misfire error at the prompt screen of the machine. According to the technician in charge, the error occurs maybe because of the sample is too wet. Thus, the moisture content of the POME sample is removed and the dry POME is retest for its calorific value. However, misfire error still occurs. The possible reason for this problem is the end pond POME does not contain any volatile material.

Therefore, the quality of the POME sample is changed from end pond POME to third pond POME and the calorific value of the third pond POME is not able to be determined. Then, the quality of the POME sample is changed to first pond POME. The calorific value for the first pond POME is tested and can be determined. The samples will be used for other tests.

4.2 Sample Preparation

The initial weight and final weight of the samples are recorded in Table 4.2.1 and the moisture contents of the samples are calculated.

Samples	Initial weight, w_1 (g)	Final weight, w_2 (g)	Moisture content (%)
POME (first pond)	100	77.951	22.049
POME (third pond)	100	45.895	54.105
POME (end pond)	100	38.273	61.727
Mesocarp fibre	40	31.626	20.935

Table 4.2.1. The initial weight, final weight and moisture content of the samples.

The moisture content of the samples is calculated by using the following equation and the calculation example is shown by using the first pond POME data.

$$moisture\ content = \left(\frac{w_1 - w_2}{w_1}\right) x\ 100\%$$

$$= \left(\frac{100 - 77.951}{100}\right) x\ 100\%$$

$$= 22.049\%$$

From the moisture content data of the three different quality of POME, we can find out that the moisture content of the POME increases from pond to pond. After removing the moisture content of the first pond POME, we can find out that the sample is oily but the third and end ponds POME do not oily. This is because the treatment of POME is to remove the residue oil before disposing the POME to the environment. Thus, the first pond POME is oil-base POME meanwhile the third and end ponds POME is water-base POMEs. This maybe the reason of the calorific values of first pond POME can be determined while the third and end ponds of POME cannot be determined.

4.3 Study of Element Content of Samples

The carbon, hydrogen, nitrogen and sulphur content of the samples are tested and the results are shown in Table 4.3.1, Table 4.3.2, Table 4.3.3 and Table 4.3.4 respectively. The four elements results are also plotted in graphs in Figure 4.3.1, Figure 4.3.2, Figure 4.3.3 and Figure 4.3.4 respectively.

By referring the data in Table 4.3.1 and Table 4.3.2, we can find out that the carbon and hydrogen contents in the samples decreases as the weight percentage of POME in the samples decreases. Material with high carbon and hydrogen contents will release large quantity of energy when the material is being burned. This proves that the 100: 0 POME to mesocarp fibre briquette will have the highest calorific value among all the samples tested.

Samples POME : fibre	Carbon Content (%)					
	Test 1	Test 2	Test 3	Means	Maximum	Minimum
100 : 0	65.75	50.46	63.91	60.04	65.75	50.46
75 : 25	58.99	56.76	60.04	58.60	60.04	56.76
50 : 50	55.03	48.71	54.76	52.83	55.03	48.71
25 : 75	52.01	50.78	51.16	51.32	52.01	50.78
0 : 100	51.30	46.00	46.52	47.94	51.30	46.00

Table 4.3.1. The carbon content (%) of the samples.

Samples POME : fibre	Hydrogen Content (%)					
	Test 1	Test 2	Test 3	Means	Maximum	Minimum
100 : 0	12.060	8.337	10.320	10.239	12.060	8.337
75 : 25	8.738	7.899	8.531	8.389	8.738	7.899
50 : 50	7.090	5.649	6.944	6.561	7.090	5.649
25 : 75	6.147	5.999	6.095	6.080	6.147	5.999
0 : 100	6.175	5.066	5.348	5.530	6.175	5.066

Table 4.3.2. The hydrogen content (%) of the samples.

Samples POME : fibre	Nitrogen Content (%)					
	Test 1	Test 2	Test 3	Means	Maximum	Minimum
100 : 0	1.133	1.161	1.059	1.118	1.161	1.059
75 : 25	1.222	1.105	1.157	1.161	1.222	1.105
50 : 50	1.205	1.235	1.103	1.181	1.235	1.103
25 : 75	1.225	1.158	1.224	1.202	1.225	1.158
0 : 100	1.228	1.154	1.371	1.251	1.371	1.154

Table 4.3.3. The nitrogen content (%) of the samples.

Samples POME : fibre	Sulphur Content (%)					
	Test 1	Test 2	Test 3	Means	Maximum	Minimum
100 : 0	0.971	0.592	0.766	0.776	0.971	0.592
75 : 25	0.601	0.499	0.654	0.585	0.654	0.499
50 : 50	0.371	0.221	0.358	0.317	0.371	0.221
25 : 75	0.268	0.289	0.273	0.277	0.289	0.268
0 : 100	0.283	0.197	0.277	0.252	0.283	0.197

Table 4.3.4. The sulphur content (%) of the samples.

By comparing the results of the 0: 100 POME to mesocarp fibre briquette with the data in Table 1.2.2, it is found out that there has small different between the study and the literature. This small difference is acceptable because the physical properties of the mesocarp fibre depend on the environment condition.

From the data in Table 4.3.3 and Table 4.3.4, it is found out that the nitrogen and sulphur contents in the samples are low. This means that the samples will not create major environment pollution such as acid rain when the samples are being burned.

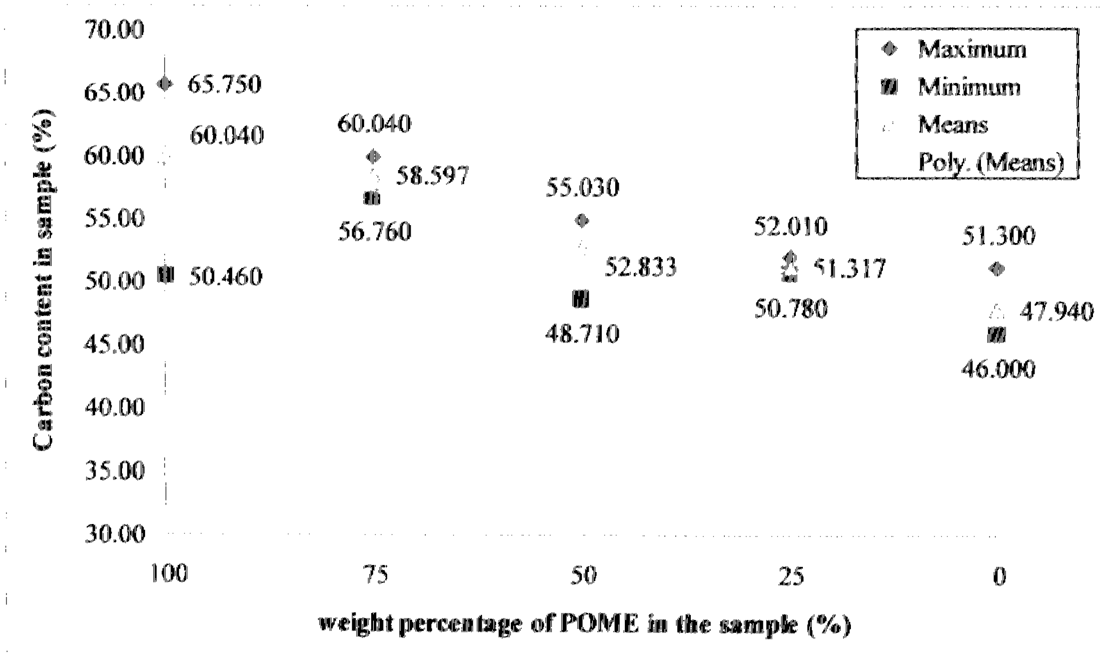


Figure 4.3.1. The carbon content (%) of the samples.

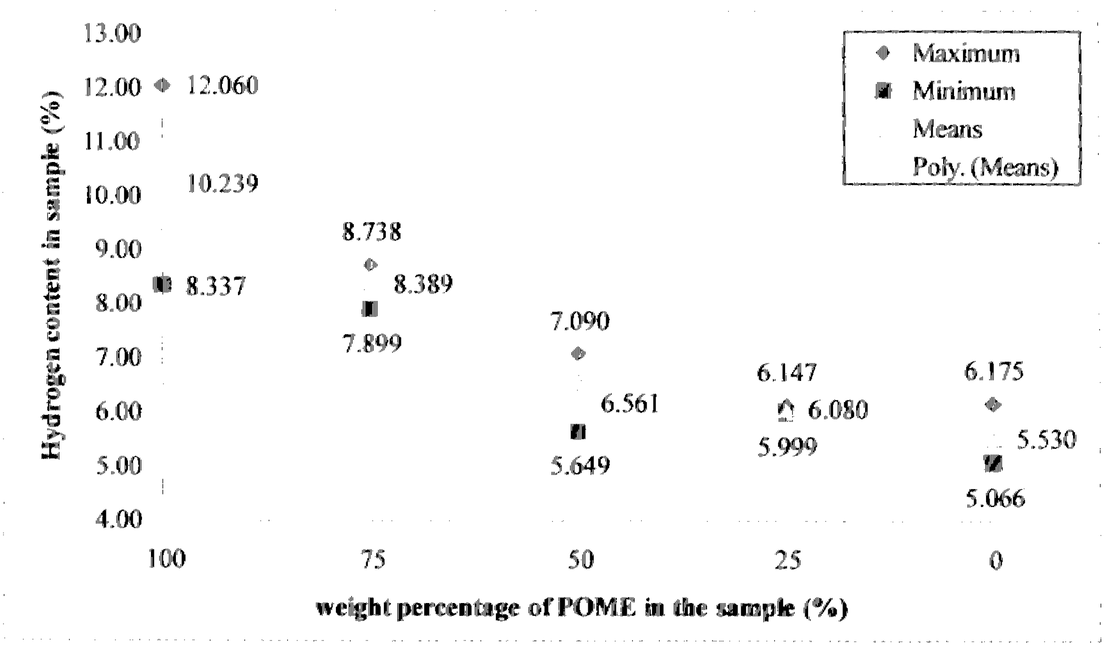


Figure 4.3.2. The hydrogen content (%) of the samples.

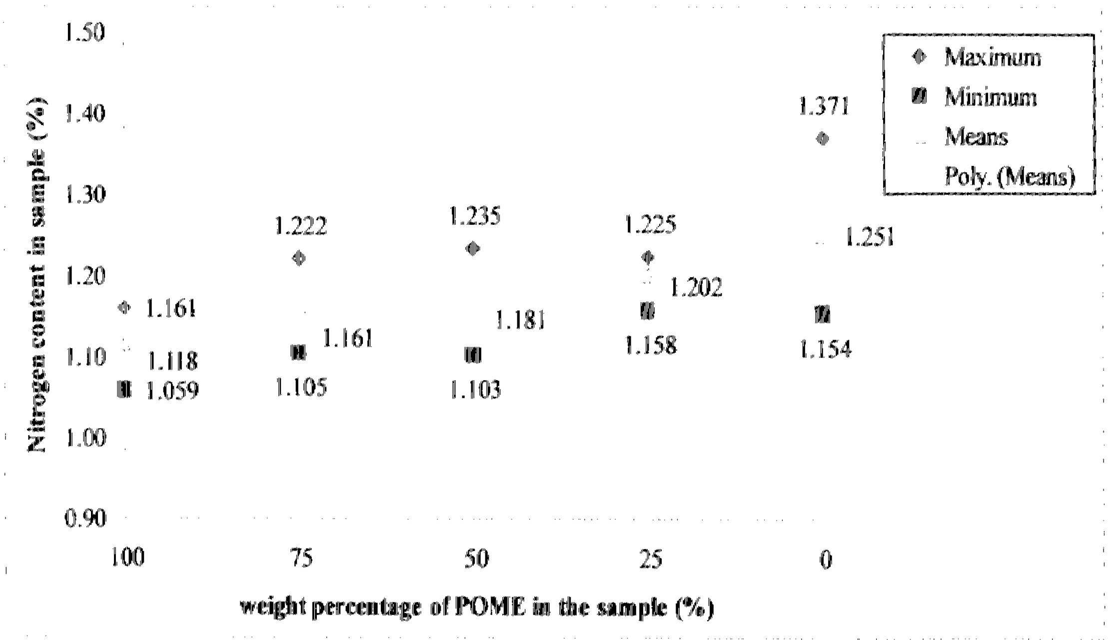


Figure 4.3.3. The nitrogen content (%) of the samples.

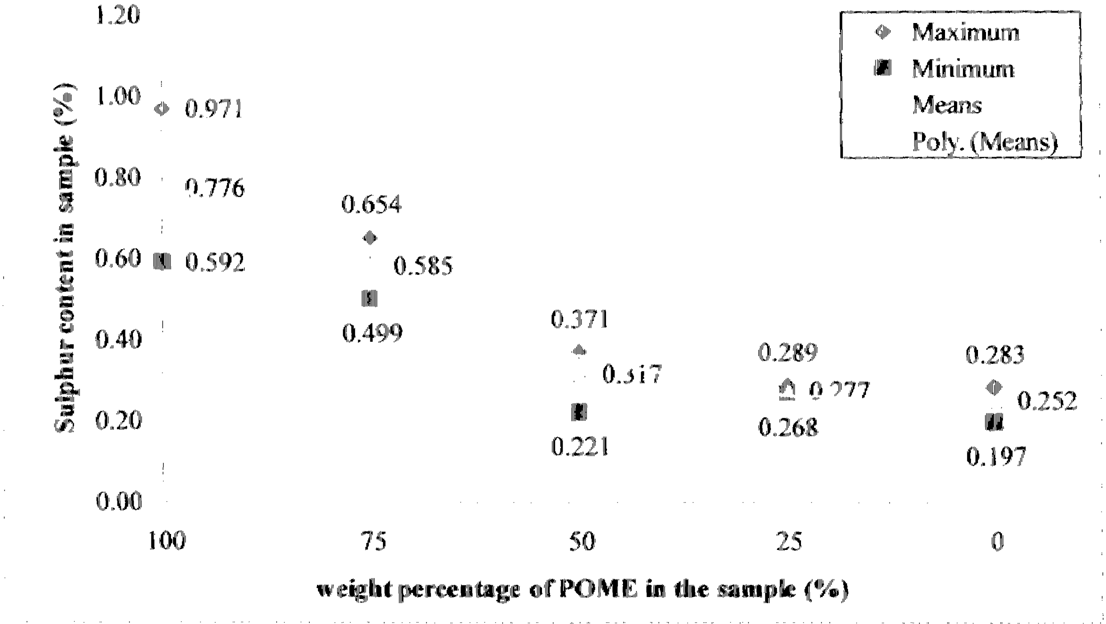


Figure 4.3.4. The sulphur content (%) of the samples.

4.4 Production of Briquette

The heights, weights and density of the briquettes produced from the samples are listed in Table 4.4.1, Table 4.4.2 and Table 4.4.3 respectively. The inner diameter of the mould is 4cm.

Samples (POME : fibre)	Heights of briquettes, h (cm)				
	No.1	**No.2**	**No.3**	**No.4**	**No.5**
100 : 0	0.65	0.65	0.75	0.72	0.65
75 : 25	0.75	0.75	0.71	0.75	0.7
50 : 50	0.75	0.8	0.75	0.8	0.77
25 : 75	0.8	0.82	0.8	0.82	0.8
0 : 100	0.85	0.85	0.83	0.84	0.85

Table 4.4.1. The height of the briquettes produced.

From the data in Table 4.4.1, it is found out that the 100: 0 POME to mesocarp fibre briquette has the smallest value of height. With the reducing of POME weight percentage and increasing of mesocarp fibre weight percentage in the briquettes, the height of the briquettes keep on increasing. This is because the POME is soft and is oil base and thus, it is easier to be compressed than the mesocarp fibre. From the data, we can conclude that the compressibility of the samples is as shown in Figure 4.4.1.

100 : 0 > 75 : 25 > 50 : 50 > 25 : 75 > 0 : 100

Figure 4.4.1. The compressibility of the samples (from highest to lowest) at ratio of POME to mesocarp fibre.

Samples (POME : fibre)	Weights of briquettes, w (g)				
	No.1	No.2	No.3	No.4	No.5
100 : 0	7.9060	7.9239	8.1623	8.0904	7.5908
75 : 25	8.5641	8.3185	8.5592	8.8551	8.4714
50 : 50	8.5687	9.5212	8.6443	9.6834	8.9269
25 : 75	9.6055	9.8703	9.5884	9.7502	9.6968
0 : 100	10.0337	10.0446	9.9908	10.0305	10.0455

Table 4.4.2. The weight of the briquettes produced.

From the data in Table 4.4.2, we can find out that the weights of the briquettes produced are not fall in the range of 9.95g to 10.05g (except for 0: 100 POME to mesocarp fibre briquettes) even though the initial weight of the samples are fall between 9.95g to 10.05g. Initial weight is the weight of the sample measured before compressing into briquette form. During the producing of the briquettes, it is found out that oil is being compressed out for the samples which contain POME. The more POME weight percentage in the sample, the more oil is being compressed out. This is the reason of the reducing of weight of the briquettes which contain POME.

Samples (POME : fibre)	Density of briquettes, ρ (g/cm^3)					
	No.1	No.2	No.3	No.4	No.5	Mean
100 : 0	0.9678	0.9700	0.8659	0.8941	0.9292	0.9254
75 : 25	0.9086	0.8825	0.9592	0.9394	0.9629	0.9305
50 : 50	0.9090	0.9470	0.9171	0.9631	0.9225	0.9317
25 : 75	0.9554	0.9577	0.9537	0.9461	0.9644	0.9555
0 : 100	0.9392	0.9403	0.9578	0.9501	0.9403	0.9455

Table 4.4.3. The density of the briquettes produced.

4.5 Burning Test

The ignitability time, the time taken to burn the briquette into ash and the ash content are recorded in Table 4.5.1. The method to calculate the ash content is shown by using the data of 100: 0 POME to mesocarp fibre briquette.

Samples (POME : fibre)	Ignitability time (s)	Time taken to burn to ash (s)	Initial weight (g)	Final weight (g)	Ash content (%)
100 : 0	100	540	9.7777	0.6327	6.47
75 : 25	90	525	9.8101	0.8714	8.89
50 : 50	80	515	9.8314	0.9260	9.42
25 : 75	60	500	9.9142	1.029	10.38
0 : 100	50	490	9.9695	1.2744	12.78

Table 4.5.1. The ignitability time, time taken to burn to ash and ash content of the samples.

$$ash\ content\ (\%) = \frac{final\ weight}{initial\ weight}\ x\ 100\%$$

$$= \frac{0.6327}{9.777}\ x\ 100\%$$

$$= 6.47\%$$

From the data in Table 4.5.1, we can find out that the ignitability time increases with the addition of POME in the samples. The 100: 0 POME to mesocarp fibre briquette has the highest ignitability time while the 0: 100 POME to mesocarp fibre briquette has the lowest ignitability time. The ignitability time of a good quality biomass briquette has to be as short as possible. During the burning of the samples of briquettes which contain POME, it is observed that oil is being heated out from the briquettes. The heat energy is being absorbed by the solid POME and to melt the solid POME to become oil. Thus, the ignitability time of the briquettes which contain POME becomes longer.

The time taken to burn the briquette into ash for a good quality biomass briquette should be as longer as possible. The 100: 0 POME to mesocarp fibre briquette has the longest time taken to burn into ash among all the samples.

The ash content of the biomass briquettes are decreasing with the increase of POME content in the samples. There has no flying ash when the samples briquettes are burned.

4.6 Drop Test

The results of the test are shown in Table 4.5.1. From the images in Table 4.6.1, we can find out that the 100% mesocarp fibre briquette is the most brittle. Crack is obviously observed for the 0: 100 POME to mesocarp fibre briquette after the first drop test is done. Part of the briquette has broken too during the first drop test. At the second drop test, the briquette has broken into many small pieces. Therefore, the briquette is not able to be weighed and cannot continue to carry out the other drop tests.

The 25: 75 POME to mesocarp fibre briquette is able to continue to second drop test. After the first drop test, the physical outlook of the briquette has no change. The weight of the briquette has reduced for 0.886g after the first drop test. The briquette breaks into 2 major pieces when the second drop test is carried out and thus, the briquette is not able to carry out other drop tests.

The 50: 50 POME to mesocarp fibre briquette has better result than the previous samples. There has no any physical defect found on the briquette after the first and second drop tests are carried out. After the third drop test, minor crack is found on the briquette (shown by the red arrow in the image). After the forth drop test, the crack on the briquette becomes more obvious but the briquette does not break into pieces.

There has nothing changed to the physical outlook of the 75: 25 POME to mesocarp fibre briquette after the first, second and third drop test. Deformation of briquette and crack started to be seen on the briquette after the forth drop test but the briquette is not break into pieces.

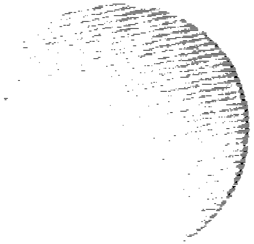
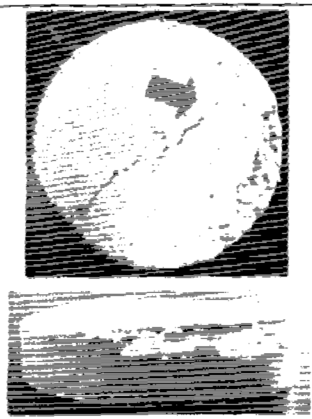
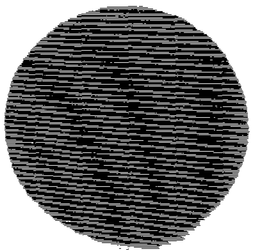
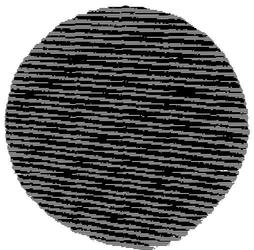
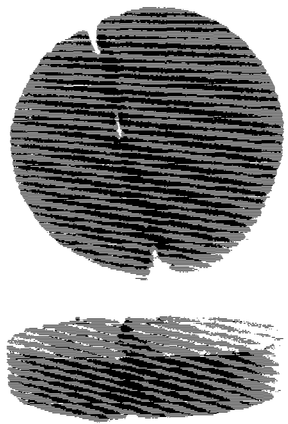
The 100: 0 POME to mesocarp fibre briquette is the most ductile among all the samples. There has nothing physical change to the briquette after the first, second and third drop tests are carried out. Deformation of briquette is found after the forth drop test is carried out. The deformation of the briquette is shown by the yellow arrow in the image of Table 4.6.1.

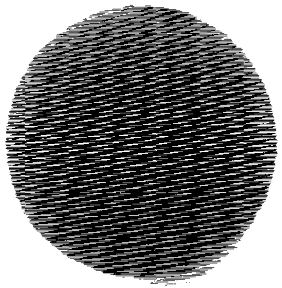
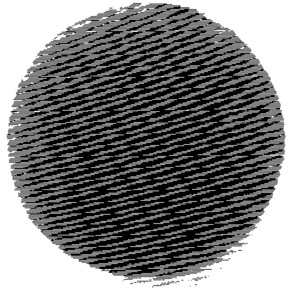
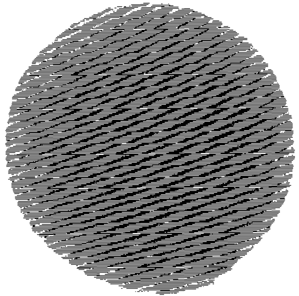
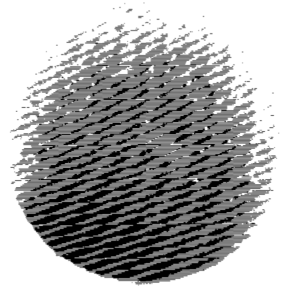
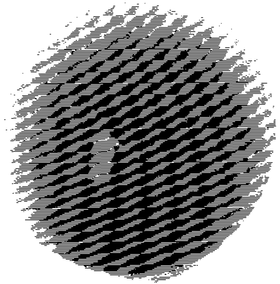
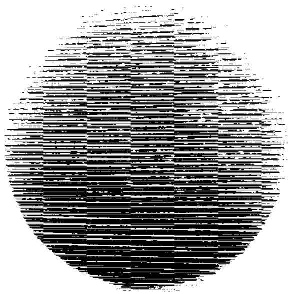
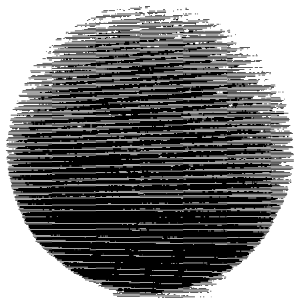
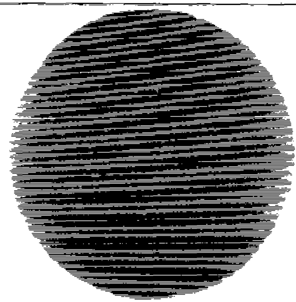
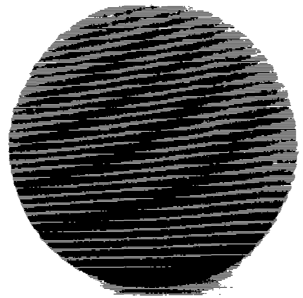
100 : 0	>	75 : 25	>	50 : 50	>	25 : 75	>	0 : 100

Figure 4.6.1. The brittleness of the samples (from the most ductile to the most brittle) at ratio of POME to mesocarp fibre.

The brittleness of the samples (from the most ductile to the most brittle) is shown in Figure 4.6.1. From the data in Table 4.4.1, it is found out that the thickness or heights of the briquettes also play an important role in the drop test. The lesser the thickness of the briquette, the easier deformation of briquette happening. Deformation of briquette may lead to the happening of crack and thus broken of briquette.

During the producing of the sample-mixed briquettes, oil is compressed out and part of the oil is being absorbed by the mesocarp fibre. The oil act as binder and the POME and mesocarp fibre in the mixture are being tight up together and thus, these briquettes become harder and will not break easily. These briquettes will not break into many small pieces if compare to the 0: 100 POME to mesocarp fibre briquette.

Samples POME : fibre	Image, height and weight of sample (before drop test)	Image and weight of samples (after drop test)			
		First drop test	Second drop test	Third drop test	Forth drop test
0 : 100	 Height: 0.83cm Weight: 9.9908g	 Weight: 9.7933g	 Weight: unable to be weighed	Briquette fails to continue the test	Briquette fails to continue the test
25 : 75	 Height: 0.82cm Weight: 9.8703g	 Weight: 9.7817g	 Weight: 9.7503g	Briquette fails to continue the test	Briquette fails to continue the test

50 : 50	 Height: 0.80 cm Weight: 9.6834g	 Weight: 9.6084g	 Weight: 9.6030g	 Weight: 9.5915g	 Weight: 9.5881g
75 : 25	 Height: 0.75 cm Weight: 8.3185g	 Weight: 8.3144g	 Weight: 8.2913g	 Weight: 8.2885g	 Weight: 8.2706g

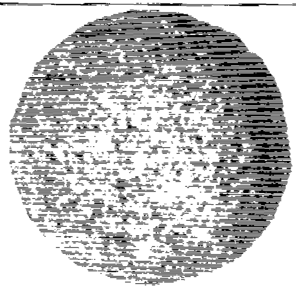
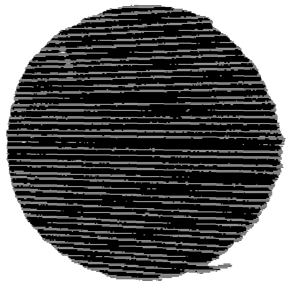
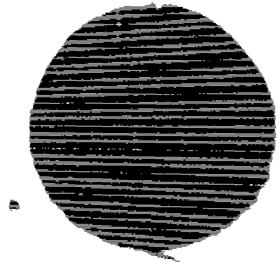
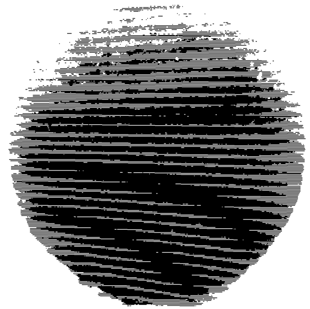
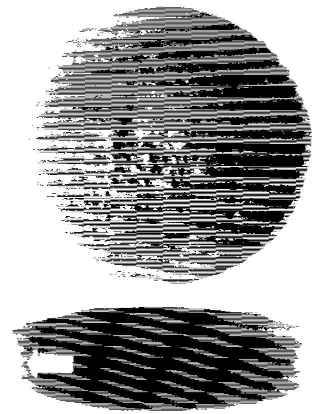
100 : 0	 Height: 0.65 cm Weight: 7.9060g	 Weight: 7.8992g	 Weight: 7.8979g	 Weight: 7.8973g	 Weight: 7.8947g

Table 4.6.1. The results of drop tests for the samples (red arrow shows the position of crack while yellow arrow shows the position of deformation).

4.7 Second Section of Calorific Value Test

The calorific values for the wet POME and wet mesocarp fibre are listed in Table 4.7.1 while Table 4.7.2 lists the calorific values for the dry samples. From the data, we can find out that the wet POME has lower calorific value (at range of 22206 kJ/kg to 23602 kJ/kg) if compare with the dry POME (at range of 32920 kJ/kg to 34595 kJ/kg). The wet mesocarp fibre also has lower calorific value if compare with dry mesocarp fibre. This is because incomplete burning occurs to the samples with moisture content. Thus, dry POME will be used to mix with dry mesocarp fibre for different ratio and the calorific values of the mixture samples are determined.

Sample	Calorific value (kJ/kg)					
	Test 1	Test 2	Test 3	Mean	Maximum	Minimum
POME	23602	22206	23166	22991.33	23602	22206
Mesocarp fibre	14488	14786	14837	14703.67	14837	14488

Table 4.7.1. Calorific values for the wet POME and wet mesocarp fibre.

Sample	Calorific value (kJ/kg)					
POME : fibre	Test 1	Test 2	Test 3	Mean	Maximum	Minimum
100 : 0	34595	32920	32970	33495	34595	32920
75 : 25	28169	28545	28177	28297	28545	28169
50 : 50	25699	25080	25178	25319	25699	25080
25 : 75	21862	20366	20502	20910	21862	20366
0 : 100	20494	20122	19294	19970	20494	19294

Table 4.7.2. Calorific values for the dry POME, dry mesocarp fibre and the mixture with different ratio.

In section 4.4, it is mentioned that oil is being compressed out during the production of the briquettes which contain POME. Thus, the calorific values of the 100: 0 POME to mesocarp fibre briquettes are tested and are compared with the raw dry POME calorific value. The results show that both the calorific values are nearly similar and this shows that the compress of oil during the production of briquette will not affect the results of the calorific value test.

Table 1.2.2 shows the calorific values and moisture contents of EFB, mesocarp fibre and shell. The small difference between the study and the literature is acceptable because the physical properties of the POME and mesocarp fibre depend on the environment condition and the harvesting season.[10] Figure 4.7.1 is the graph of the mean calorific value of the three tests versus the weight percentage of mesocarp fibre. Figure 4.7.2 is the graph of the range of the calorific values of the samples.

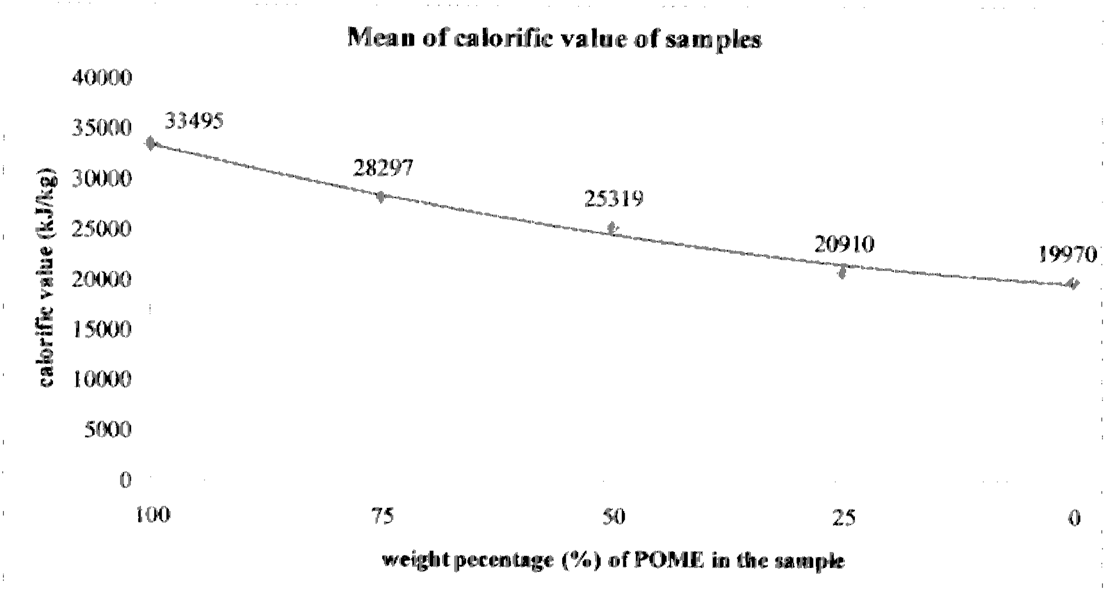


Figure 4.7.1. Graph of mean calorific value of the samples versus the weight percentage of POME.

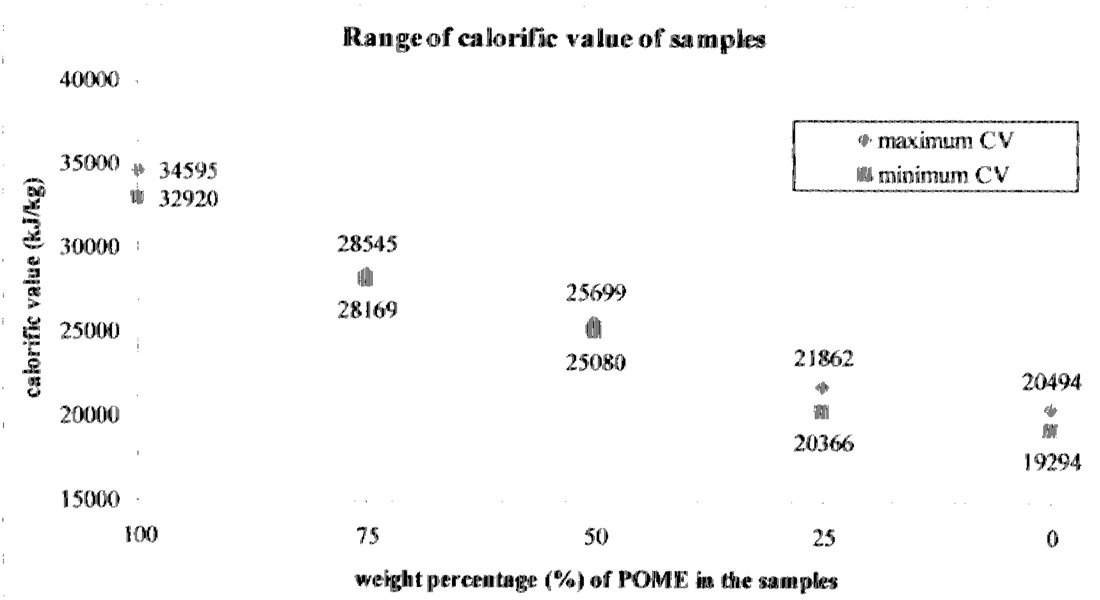


Figure 4.7.2. Graph of the range of the calorific values of the samples.

From the graph, we can find out that the calorific values of the samples decrease with the increasing of the mesocarp fibre weight percentage in the sample. This is because the POME sample used in the study is first pond POME, which is an oil base POME. The reducing of POME weight percentage in the mixture has reduced the oil content in the samples and thus, the calorific values of the samples will decrease.

At the end of the research, it is informed by the manager of the palm oil mill that the first pond POME contains CPO. The manager states that the palm oil mill was built 30 years ago and the machines and systems in the mill were very old. The sticky POME will block the pipe, which transfer the POME from the clarifiers to the open lagoon. During the clogging of the POME, CPO will be purge out from the clarifiers to the open lagoon together will the POME. Thus, the first pond POME contains CPO and has high calorific value, which is higher than the calorific value of coal (26000 kJ/kg). [26]

CHAPTER 5

CONCLUSION

The burning test result shows that the 100: 0 POME to mesocarp fibre briquette has the longest ignitability time, longest time taken to burn into ash and lowest ash content. A good quality of biomass briquette should has low ash content, short ignitability time and longer time taken to burn into ash. Longer ignitability time is the disadvantage of a biomass briquette because more time is taken to ignite the briquette and indirectly, more heat energy is wasted.

The first pond POME contains CPO, whereby the CPO is purged out from the clarifiers during the clogging of the POME. Thus, the results of the research may not accurate. However, the finding of the research shows that the 100: 0 POME to mesocarp fibre briquette has the highest calorific values among the samples. The mean calorific value of the 100: 0 POME to mesocarp fibre is 33495 kJ/kg. Besides, the results of the element content test shows that the sample POME contains high value of carbon and hydrogen and contains less value of nitrogen and sulphur. This means that the burning of raw POME will not create major air pollution such as acid rain. Thus, the palm oil mill can use the first pond POME as boiler fuel in order to reduce the operating cost of the company.

Since the palm oil mill manager informed about the problem with the first pond POME at the very last minute, there has no time to re-conduct the research by using another quality of POME from different palm oil mill. However, from the literature, Table 2.2.6.1 shows that the calorific value of the POME is 16992 kJ/kg. Even though the percentage of CPO in the first pond POME is unknown, it can be sure that the POME contains low nitrogen and sulphur values since the first pond POME from the palm oil mill (mixture of CPO and POME) has low nitrogen and sulphur values. Therefore, the POME has the potential to become new biomass energy.

The objectives of the research (which are to find out the potential waste reduction from POME, to study the element content of the POME and the energy level of the POME mixed with different percentage of mesocarp fibre) are achieved.

CHAPTER 6

RECOMMENDATIONS

Research has to be done by using different quality of POME from different palm oil mill. Further research has to be done to test the gas emission result from the burning of the POME. This is to make sure the gas emission is not toxic and do not contain any particle or dust which will cause health problem to human.

Besides, biomass gasification analysis can be done to the gas emission of the burning of the POME. Biomass gasification is the incomplete combustion of the biomass and produce combustible gases such as carbon monoxide, hydrogen, and methane.[27]

Furthermore, stability test can be carried out to find out the environment effects on the POME. This can determine the storing environment of the POME in order to make sure the POME is in the optimum condition.

Moreover, the palm oil mill, which provides the samples for the research, should upgrade or improve the system and machine of the factory. It is not an industrial practice to purge out the CPO during the clogging of the POME.

CHAPTER 7

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